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The Implications of Handling Qualities in Civil Helicopter Accidents Involving Hover and Low Speed Flight

Daniel C. Dugan and Kevin J. Delamer (CDR-USN)
National Rotorcraft Technology Center
Ames Research Center, Moffett Field, California

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National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

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The Implications of Handling Qualities in Civil Helicopter Accidents Involving Hover and Low Speed Flight

Daniel C. Dugan[1] and Kevin J. Delamer (CDR-USN)[2]

Ames Research Center

ABSTRACT

Because of increasing accident rates in <u>Army</u> helicopters in hover and low speed flight, a study was made in 1999 of accidents which could be attributed to inadequate stability augmentation. A study of <u>civil</u> helicopter accidents from 1993–2004 was then undertaken to pursue the issue of poor handling qualities in helicopters which, in almost all cases, had no stability augmentation. The vast majority of the mishaps studied occurred during daylight in visual meteorological condition, reducing the impact of degraded visual environments (DVE) on the results. Based on the Cooper-Harper Rating Scale, the handling qualities of many of the helicopters studied could be described as having from "very objectionable" to "major" deficiencies. These costly deficiencies have resulted in unnecessary loss of life, injury, and high dollar damage. Low cost and lightweight augmentation systems for helicopters have been developed in the past and are still being investigated. They offer the potential for significant reductions in the accident rate.

INTRODUCTION

Concerned by a trend of increasing accident rates, Key published the results of a survey of accidents that occurred during hover and low speed flight involving four types of Army helicopters (ref. 1). The implications of handling qualities deficiencies in the accidents analyzed in these pilot error mishaps were of primary interest. The helicopters studied spanned the range from the OH-58D Kiowa, a small reconnaissance helicopter, to the large cargo transport CH-47, and included the AH-64 Apache attack helicopter and the UH-60 Blackhawk. All of these aircraft were equipped with a rate command stability augmentation system (SAS) which provides pitch, roll, and yaw rate damping inputs of small magnitude at relatively high frequency to the control system. These helicopters had been flight tested and their handling qualities were assessed as marginal. It was Key's contention that the modification of the rate command systems to provide attitude command response would significantly reduce the accident rates. With an attitude command system the control augmentation generally has increased authority, and attitude changes are proportional to stick displacement. Motivated by these results and conclusions, a study of civil helicopter accidents was undertaken to pursue the issue of handling qualities and the role that they might play in causing or contributing to mishaps. National Transportation Safety Board (NTSB) accident summaries were studied and analyzed for the period 1993–2004 (ref. 2). Only hover, hover taxi, and low speed flight summaries were considered, as these represented a significant but bounded portion of the total number of mishaps (fig. 1). In addition to limiting the scope of the inquiry to a manageable level, this data set examined a unique aspect of rotorcraft operations which accounted for a significant portion of the civil rotorcraft mishaps. It also aligned the study with the results of the earlier Key study of military accidents. The accidents that were analyzed in this current study occurred, with a few exceptions, on helicopters that had no stability and control augmentation and furthermore, in daylight conditions without DVE. Referencing the Cooper-Harper Handling Qualities Rating Scale (ref. 3), it is the authors' opinion that the handling qualities of a large number of the helicopters involved could be categorized as having from "very objectionable" to "major" deficiencies. Furthermore, it implies that extensive pilot compensation is required for adequate performance and, in the worst cases, considerable compensation is required to maintain control of the helicopter under adverse conditions.

[1] Deputy Director, National Rotorcraft Technology Center, Ames Research Center, Moffett Field, CA 94035.
[2] CDR-USN, Navy Liaison Officer, National Rotorcraft Technology Center, Ames Research Center, Moffett Field, CA 94035.

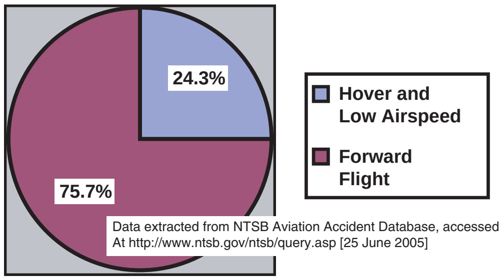

Figure 1. Hover and Low Airspeed Helicopter Mishaps 1993–2004 (as a Percentage of All Helicopter Mishaps).

With few exceptions, the accidents reviewed resulted in substantial damage, or in some cases the destruction of the helicopter. This is not surprising since any time the main rotor or tail rotor of a helicopter contacts the ground, substantial damage will result. The NTSB does not assign a dollar value to damage classified as "Substantial," and the definition is very broad in scope: "substantial damage means damage or structural failure that adversely affects the structural strength, performance, or flight characteristics of the aircraft, and that would normally require major repair or replacement of the affected part." Large sums may be spent to repair damage from accidents that do not meet the NTSB Part 830 definition of "substantial damage."

BACKGROUND

A study of recent (1963–1997) helicopter accidents in the U.S. (ref. 4), attributed 1,114 accidents, or 13.2% of the accidents studied, to loss of control. In the categories of single engine piston and turbine helicopters, these accidents resulted in 247 fatalities, 228 serious injuries, and 319 helicopters destroyed. These categories of helicopters generally do not have stability and control augmentation systems installed or available. It would not be possible to speculate, without a detailed study of each event, that any particular number or percentage of these accidents could have been prevented by the incorporation of rate or attitude command control augmentation into the flight control systems. Many of the occurrences studied in reference 4 undoubtedly were also analyzed in this current study, since the time periods overlapped for some of the years. Isler and De Maio (ref. 5) noted that the chain of accident events for personal and instructional missions in a large number of helicopter accidents began with loss of control. These accidents, for the low cost category of helicopters, accounted for 48.2% of the total accidents.

In 1998, a Final Report of the joint Department of Defense, Federal Aviation Administration, and the National Aeronautics and Space Administration Helicopter Accident Analysis Team was published (ref. 6). It was surprising to note throughout the report that there was no mention of poor handling qualities, nor the resulting failure of the pilot to maintain control of the helicopter, as factors in any of the accidents reviewed from NTSB data. The FAA's National Aviation Safety Data Analysis Center (NASDAC) reports were not included, nor were there recommendations in the Safety Investments section of the report (ref. 6) to improve the designs of control systems to enhance the handling qualities of the helicopters. As a result of the Accident Team's report, a workshop was held in July of 1998 in response to the recommendations of that body. Subsequently, a report entitled "Near Term Gains in Rotorcraft Safety—Strategies for Investment" was published in February, 1999 (ref. 7). Although statistics were discussed which tied many mishaps to "loss of control," once again there were no recommended actions to improve civil rotorcraft safety by the improvement of helicopter handling qualities. Emphasis was placed on training, obstacle protection, risk management, accident analyses, and even the use of night vision goggles.

ANALYSIS

The assessment of the accident reports reviewed has, by necessity, involved qualitative and subjective judgments by the authors. The obvious cases that did not involve handling qualities, such as attempting to takeoff to a hover with one skid tied down, were easily eliminated from consideration. There were also cases where pilots ran out of available power, which often resulted in a loss of main rotor RPM and subsequently a loss of control authority—especially in the yaw axis. Controlled descents into the ground, in many cases, also had to be discounted, as did mechanical failures that resulted in loss of control. Others involving loss of tail rotor control power or authority were more difficult. In many cases, hovering downwind or in a stiff crosswind might have resulted in an accident by a pilot with low experience; however, the experienced pilot could work his way through the condition without losing control. A student or low time pilot will, in many cases, over-control the helicopter and use all of the available control authority. There were many cases where precision was required while hovering near obstacles. Often in these cases, little or no position drift could be tolerated. At times, depending on the winds and terrain, a "skids level" attitude was imperative at touchdown to avoid the potential for a rollover or fore/aft pitching which could cause main rotor or tail rotor contact with the terrain.

A total of 547 accidents were thoroughly reviewed from the years 1993–2004. Initially, the accidents reviewed involved only those occurring in hovering or near hovering flight. This review was expanded to include many accidents which occurred in low speed flight either during takeoffs, approaches to landing, or low speed maneuvering. Of the total, 126 (or 23%) could be attributed to loss of control by the pilot which was caused or aggravated by inadequate or deficient handling qualities. There were also ten accidents that involved gyroplanes or gyrocopters and these were discarded from the matrix. It was noted that there were three fatalities, one serious injury, and four minor injuries attributed to these ten single pilot/occupant accidents. Pilot experience was typically low and it may be inferred that flying this type of hybrid rotorcraft is particularly challenging for inexperienced, though adventurous, aviators.

Many manufacturers were represented in the accident statistics as compared to the four models studied by Key (ref. 1). Fifteen different manufacturers were listed to include homebuilt or kit helicopters consolidated as one category. There were over thirty various models represented.

MISHAP SUMMARY EXAMPLES

A few summary examples of mishaps reviewed illustrate the potential improvement in helicopter safety and reduction in accidents that could be achieved if helicopter handling quality were improved by the addition of stability and control augmentation systems. While these cases involve egregious examples of handling qualities deficiencies, they are unfortunately all too representative of the accidents studied:

Case 1: This flight involved a surplus UH-1H helicopter operated by the Tennessee Valley Authority in daylight under moderate, downwind wind conditions (9 knots gusting to 19 reported at an airport 5 miles east of the mishap site). It had flown for 1.2 hours before the pilot attempted to come to an OGE hover over a power pole for the attachment of an external load. Commands were given to the pilot to “ease the aircraft down and hold position; move left and move right.” The helicopter drifted to the left and forward. After this, a command to back off and try again was followed by repetitive “move left” commands. The main rotors struck a workman on the pole, the pole itself, and the helicopter rolled right in a descent and struck the ground. There were no engine or flight control malfunctions and the pilots were highly qualified. Four fatalities and one minor injury resulted from this accident. This was a precision task for an external load hookup in an OGE hover in an unaugmented helicopter. It is our contention that an improved control system, to include stability augmentation, could have enabled the pilot to achieve the high degree of precision required to hold position and complete the hookup.

Case 2: A single engine, turbine powered, teetering rotor helicopter crashed in snow covered terrain in daylight under Visual Meteorological Conditions (VMC) with 1 mile visibility. The pilot was attempting to land next to a snow gauging station and he flew past it. With the snow cover and reduced visibility, the pilot had poor visual references and allowed the skids to contact the terrain. Collective pitch was applied, the pilot attempted to stabilize the helicopter in hover, but it drifted forward and to the left. The left skid contacted the terrain and the helicopter rolled on its left side. Although there were no injuries to the three on board, the helicopter was destroyed. The whiteout conditions encountered resulted in a classic loss of control in a degraded visual environment. An effective stability augmentation system could have allowed the pilot to maintain a level attitude, hold position, and either land level, pull up for another landing attempt, or abort the mission.

Case 3: A single engine (piston) helicopter was to be flown on a maintenance test flight for track and balance of the main rotor. The pilot suddenly applied collective pitch for takeoff and the helicopter rose to about four feet and began to yaw left and right and then pitch forward and aft. The pilot attempted to stabilize the helicopter, but the main rotor blades struck the ground to the front and the helicopter rolled on to its right side. There were no injuries to the pilot or mechanic, but the damage incurred was substantial. In this case, abrupt and excessive control application caused the pilot to lose control of the unstable helicopter in hover. Although the pilot’s control manipulation and activity were determined to be the cause of the accident, perhaps he could have recovered if the helicopter had been a more stable platform through the incorporation of stability augmentation.

Case 4: On a dual instructional flight, a Student Pilot (SP) lifted the single engine, piston engine, two-place helicopter to a three-foot hover. The SP then “over controlled” the helicopter and caused it to drift to the left in a descent. The left skid contacted the ground and the helicopter rolled on to its left side. There were no injuries, but the helicopter sustained substantial damage. From reading many similar accounts, these Student Pilots could use more stable helicopters that are more forgiving of their inexperience.

Case 5: In another single engine, piston engine helicopter on a dual instructional flight, the student pilot developed a high rate of descent at slow speed. A rapid application of collective resulted in an uncommanded rotation to the right which the instructor was unable to arrest. In the course of the attempt to regain rotor speed lost during that recovery, the aircraft impacted the ground and sustained significant damage.

Case 6: A high-time fixed-wing pilot with limited helicopter experience, flying a single turbine-engine helicopter, encountered an uncommanded rotation to the right. He failed to reduce the engine throttle to idle and impacted the ground after multiple rotations. The probable cause determined by the NTSB was a loss of tail rotor effectiveness (LTE) coupled with the pilot's failure to initiate a timely correction.

RESULTS

The issues which were causal factors, and which also illustrated deficiencies in handling qualities, could be grouped into four broad categories as follows:

Stability Augmentation

Helicopters are inherently less stable than airplanes. If an unaugmented helicopter in hovering flight is disturbed from equilibrium, its attitude continues to diverge until corrective control inputs are made by the pilot. Most airplanes, however, are inherently stable and when they are disturbed from equilibrium restoring moments are generated. Only so much can be done with the fundamental handling qualities of the basic helicopter and manufacturers generally design the low end helicopter to meet the minimum requirements of FAR 27. Additional aerodynamic modifications to the airframe to improve handling qualities, such as fins or strakes, are often costly, add weight, and can produce additional drag with resulting performance penalties. Many helicopters in use today do not have to meet even the minimum standards for the same class of helicopter being built under the current requirements.

In the late seventies the Helicopter Association International (HAI), then the Helicopter Association of America (HAA), held a convention in Mission Valley, California, near San Diego. The convention was located in a hotel adjacent to a golf course and helicopters were allowed to land and takeoff in a clear grassy area next to the parking lot. It was apparent from operations observed at this temporary heliport that a particular Bell 206 was very stable while hovering, landing, and taking off near the other operating helicopters. The pilot's control of pitch and roll attitude was precise with very little oscillation. From an orientation flight in the helicopter, it was determined that it was equipped with a Sfena "Mini-Stab." This package had been optimized for the pitch and roll axes, and the yaw axis augmentation was still being developed. For the hover and in-flight operations, the improvements in handling qualities were immediately apparent. The pilot workload was reduced significantly and precision was improved considerably. It was an impressive accomplishment for this small helicopter which might otherwise be described as "squirrelly" by some operators for some tasks—to include hover and hover taxi in a crosswinds and low speed flight in turbulence.

A call to the Bell 206 Product Support division in Mirabel, Canada, revealed that a stability augmentation package is not offered as an option for the Bell 206 series of helicopters. This stability augmentation system is installed in the Navy TH-57C helicopters used for advanced flight training and was required to meet military standards for certification for single-piloted instrument flight. This package was designed in the late seventies and early eighties and today's technology should permit the design of an inexpensive, lightweight stability augmentation system for even the low-end helicopters on the market. Hydraulic servo technology, where applicable, has also progressed to permit this integration at a lower cost and weight.

More recently, an Attitude Command/Attitude Hold augmentation system, HeliSAS, has been developed and tested (ref. 8). The system weighs only 12 pounds and the projected cost is $30,000. It was demonstrated on an R-44 test aircraft and was evaluated by pilots from the Robinson factory—as well as a NASA test pilot and one from the National Test Pilot School. "Very favorable" comments were received. According to the FAA, a low cost SAS has never been certificated, considerable work needs to be done to establish standards, and current rules are not adequate. If these are reasons for not proceeding, then the FAA needs to move ahead with the formulation of standards and revise the current rules. Lightweight, low cost systems such as the one described, have the potential to significantly reduce accidents attributed to poor handling qualities.

A recent simulation study at Ames Research Center (April–May 2001) began the process to look at the lowest levels of stability and control augmentation that could be used to safely operate a "low-end" helicopter single pilot under Instrument Flight Rules (IFR). It would follow that the application of even minimum levels of augmentation for instrument flight to this category of helicopter could make a significant reduction in accidents in hover and low speed flight under VMC.

Attitude or even rate stabilization can reduce the possibility of a pilot induced oscillation (PIO) developing by providing a more crisp response to control inputs about all axes and by providing the damping that permits smooth control of the helicopter's attitude and position. Overshoot and over controlling are reduced, if not eliminated, even for the novice pilot. While manufacturers and operators strive to hold down the manufacturing, acquisition, and operating costs of the lower end helicopters, perhaps it would be appropriate for operators to re-examine the costs of these "loss of control" accidents. As previously stated in this review of hover, near hover, and low speed accidents, it was common to find substantial damage or destruction of the helicopter. Substantial damage equals large expenses which the low profit margin operator cannot afford to sustain without his business being threatened. By investing additional dollars up front in the acquisition of at least a minimal stability and control augmentation system, the helicopter could be flown more safely by pilots at all experience levels with more precision and less pilot fatigue.

One particular type of operation that requires precise positioning by the pilot is the external load or sling load mission. It involves pick-up and placement of loads suspended beneath the helicopter. Often they are conducted in close proximity to obstacles and they require a high degree of precision and demand a high workload of the pilot. In this survey, 85 (or 15%) of the accidents occurred during external load operations, far exceeding the FAA determined helicopter utilization rate of 6% for this mission area (ref. 9), as shown in figure 2. Although most of these accidents could not be attributed to poor handling qualities, pilots involved in these operations need a stable platform for this precision task. Only six of the mishap aircraft in external load operations were equipped with an attitude command system. An attitude command system would have been a significant improvement for the twenty-one helicopters involved that did have stability augmentation (rate command). Any augmentation would be a step in the right direction for the helicopters involved in the remaining accidents. It was sobering to calculate the toll from these external load accidents as a matter of information. There were 38 fatalities, 26 serious injuries, and 20 minor injuries. Twenty-six helicopters were destroyed and all of the others, with one exception, incurred substantial damage. It follows that this operation can be classified as hazardous regardless of handling qualities. Precise handling qualities are dictated by the tight tolerances required for these tasks. This highlights the benefits accrued by incorporating stability augmentation in helicopters performing this mission.

Directional Control

The FAA Advisory Circular, AC-90-95, "Unanticipated Right Yaw in Helicopters" (ref. 10), states that the loss of tail rotor effectiveness (LTE) is a critical, aerodynamic flight characteristic which can result in an uncommanded right yaw rate which will not "subside" (damp) of its own accord. If not corrected, it can result in the loss of aircraft control. The AC also states that "there is a greater susceptibility for LTE in right turns. This is especially true during flight at low airspeed since the pilot may not be able to stop rotation. The helicopter will attempt to yaw to the right and correct and timely response to this uncommanded yaw is critical. The yaw is usually correctable if additional left pedal is applied immediately. If the response is incorrect or slow, the yaw rate may rapidly increase to a point where recovery is not possible."

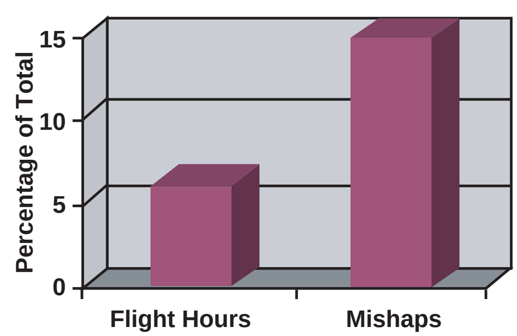

Figure 2. External Load Operations.

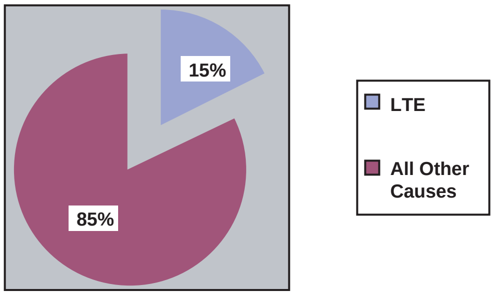

Figure 3. LTE Mishaps (as a Percentage of All Mishaps Studied).

For the accidents surveyed, 82 (or 15%) involved LTE (fig. 3). Recognizing the conditions that can lead to LTE is very important and the pilot's situational awareness is critical at all times. What direction is the wind with respect to the helicopter's heading? How much tail rotor control margin remains in terms of pedal applied? How much collective pitch can be applied before maximum available power is commanded and main rotor and tail rotor RPM start to decay? For the student or low time helicopter pilot, these in-flight judgments are often gained only through experience—which comes at a high price in too many cases. The Army and Air Force versions of the H-21 tandem rotor helicopter (unaugmented), used for a few years in the early stages of the Vietnam conflict, always acted as though it wanted to swap ends. Accordingly, the pilot workload in the yaw axis was very high.

Anyone who has flown or spent much time as a passenger in any of a long list of small, unaugmented helicopters, is aware of their directional instability. A typical maneuver, which illustrates the "squirrel like" response of the machine, is the crosswind hover or hover taxi. The pilot must constantly make high frequency pedal inputs of varying size to keep the helicopter heading in the desired direction. The tail boom dances to the right and left as the position is held or as the taxi proceeds. It is a high workload task and precision is lacking. With a capable yaw SCAS—especially one designed for attitude command—the pilot's workload and precision and the passenger's comfort are dramatically improved.

A less attractive alternative might entail building in more directional control power by improving the tail rotor design to produce more thrust, increasing engine power available to provide that thrust, and making suitable aerodynamic changes to the fuselage and tail boom designs to improve the yaw stability of the helicopter. All of these changes, where applicable and practical, could result in significant weight, cost, and performance penalties.

Teetering Rotors

In a significant number of the accidents reviewed, the helicopter's design incorporated a teetering rotor system. Of 547 accidents, 308 (or 56%) of the helicopters had teetering rotor systems (fig. 4). The numbers may, on the face of the data, be misleading. Teetering rotor systems are incorporated in helicopters that have been produced in large numbers for many years. Two manufacturers today are very successful in supplying this teetering rotor system design to the world market. One series of helicopters is relatively inexpensive (approximately $175,000 and up), powered by a piston engine, and is frequently utilized in pilot training. However, flight training by its nature accounts for a disproportionate number of mishaps. By contrast, the rigid or hingeless rotor systems tend to be incorporated in more sophisticated aircraft, employed in specific missions such as medical transport, and flown by more experienced pilots.

The semi-rigid or teetering type of rotor accomplishes blade flapping by (as the name describes) a teetering motion of the two bladed rotor system. This gives the helicopter a balanced lift distribution between the advancing and retreating blades and prevents a rolling moment from developing. The teetering system differs from articulated systems which allow individual blades to flap, and hingeless rotor systems which accomplish flapping by bending of the individual rotor blades to change their angles of attack as the blades advance and retreat. The teetering rotor, in particular, has a significant, built-in phase lag from the pilot's control input to the main rotor, until the pitching or rolling moment is generated. An absence of rate damping only aggravates the condition. This alone can cause a student pilot to put in a larger control input than is required, which eventually results in a larger roll or pitch rate than desired and can ultimately lead to PIO. Without an instructor there to damp the oscillation, a rollover can result if the main rotor or landing gear should contact the surface.

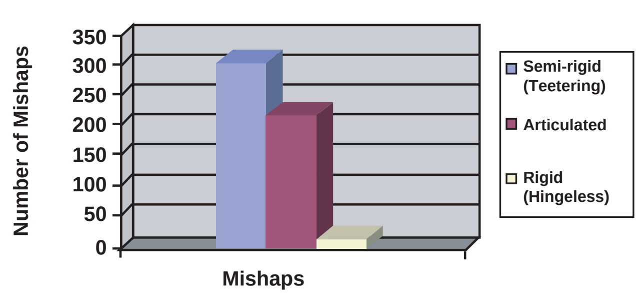

Figure 4. Mishaps by Type of Rotor System.

The teetering rotor is susceptible to conditions which can result in the rotor hub contacting the mast. This is known as mast bumping and unless it is just a very light tap, the result can be a sheared mast in flight which is usually fatal to all onboard. Unless, of course, the helicopter is at a very low altitude and airspeed (hover IGE, for instance). In the early design versions of the OH-23 (UH-12), the hub had a circular cutout for the mast. It wasn't long before a few fatal accidents took place and investigation proved that mast bumping occurred when excessive blade flapping angles allowed hub to mast contact. The fix was quite simple. The hub cutout was elongated under the blades to allow additional degrees of flapping and the serious design flaw was resolved.

In this survey, only three of the hover or low speed accidents were attributed to mast bumping with subsequent shearing and separation of the main rotor mast. These accidents did result in four fatalities, however. A single engine helicopter accident in August, 2000, near Watsonville, CA, which resulted in two fatalities, was attributed to mast bumping by an operator, demonstration team leader, and dealer. The NTSB report also stated that the probable cause was mast bumping. Although the event occurred in cruise flight, and not hover or low speed, the teetering rotor design is susceptible to this type of accident from excessive, uncoordinated, and abrupt cyclic control inputs.

For all of these disadvantages, the teetering rotor helicopter has one distinct advantage over many helicopters that use an articulated rotor system with flapping or "droop" stops. That is the ability to start or stop the rotor in much higher winds and turbulence—with or without a rotor brake. In addition, the design of the teetering rotor system's hub is not complex and it is quite rugged and reliable with low maintenance requirements. It does not have the susceptibility to ground resonance which helicopters incorporating articulated designs can encounter. Blade attachment failures for this simple design, with the resulting catastrophic loss of a blade, are rare, as compared to articulated rotor designs. These features make it a choice for many low end helicopters and also for the homebuilt market.

Instrument Flight

The first civil helicopter certificated for flight in Instrument Meteorological Conditions (IMC) in the United States was the Bell 212. In order to achieve the level of handling qualities imposed by the Federal Aviation Administration, an expensive package of instrumentation and stability augmentation improvements had to be incorporated in this twin engine helicopter. Since that time, many high end helicopters have been certificated for IFR operation to include single pilot operation. Contrast that with the long time operation of the venerable UH-1 "Huey" by the Army under Instrument Flight Rules (IFR) flying the airways and making approaches in IMC to both military and civil airports. This was done in a helicopter whose total stability augmentation consisted of the stabilizer bar mounted above and 90 degrees to the main rotor. It produced a slight damping of the main rotor displacements by its gyroscopic and inertial effect. Flying under IMC, especially in turbulence, was a high workload task in these military helicopters and it required a high degree of training and proficiency. For the civil version of these helicopters (Bell 204, 205), flight under instrument conditions is prohibited.

During the Vietnam War, the demand for helicopter pilots was so great that the practice of fully qualifying Army pilots for instrument flight was discontinued. The pipeline for pilots had to be filled as attrition and rotation to other assignments after the one year tour of duty depleted the "inventory" of pilots. As a stopgap measure, a few hours of instrument training were put in the syllabus and the pilots were awarded "Tactical Instrument Tickets." This minimal training was tailored to permit the pilot to get himself out of encounters with inadvertent IMC or, in other words, perform the 180 degree turn to fly back to visual conditions. This did not always work and many young pilots were not proficient. Add the additional complication of night conditions and the stage was set for many non-combat deaths which occurred with some regularity. Many days and nights were IMC, especially during the long rainy seasons, but the war had to go on and missions had to be flown. Many helicopters, such as the OH-6A, OH-58A, and the AH-1G, were not designated for instrument flight even by fully qualified pilots. The entire fleet of Army helicopters at that time would not meet FAA standards for instrument flight. The handling qualities were generally inadequate, most had no stability augmentation, and if so equipped, rate command was the system installed.

There have been attempts to "fix" poor handling qualities of some helicopters with the addition of avionics such as Flight Directors. While these additions can reduce the workload of the pilot and permit greater precision during the instrument approach task, they cannot improve the fundamental flying qualities of a helicopter or any aircraft. They are effectively used in combination with stability augmentation to provide the pilot with the required precision and a manageable workload. The FAA imposes standards for handling qualities as defined in the Federal Aviation Regulation (FAR) Part 27; however, these require only minimal standards. Military helicopters must meet the requirements of ADS-33D-PRF which are more stringent than those of the old MIL-H-8501. Even so, some military helicopters have had extremely poor handling qualities in the past and many of these helicopters are still in military or civilian service today.

Very few of the accidents reviewed occurred at night. Night conditions, on a cloudy or moonless night where there is no visible horizon, can often be likened to instrument conditions. It can be speculated that similar conditions can result in many accidents due to spatial disorientation. Many helicopters in use today do not have the minimum instrumentation, much less the stabilization, to be flown under real or quasi-instrument conditions—even in emergencies. The lack of any rate or attitude stabilization in the design of helicopters was continued for decades in many helicopters, both military and civil, and continues to this day.

CONCLUSIONS

From the analysis made of the accidents occurring in hover or low speed flight for this current study, it can be inferred that a significant number of previously documented accidents could have been prevented if the mishap helicopters had improved handling qualities.

From the accidents reviewed, and the other statistics on civil helicopter accidents attributed to loss of control, it is puzzling why poor handling qualities have not been pinpointed as causes or factors in the accidents. Improvements in handling qualities were not even recommended, within the scope of this research, as a means or investment in safety to reduce the frequency of such accidents.

It can be inferred that a significant reduction in accidents, injuries, and property damage could be achieved by the integration of stability augmentation systems into the control systems of the lower priced helicopters. Where this investment has already been made in the higher priced machines, the benefits of a more sophisticated augmentation system (Attitude Command) could be substantial in terms of helicopter safety.

RECOMMENDATIONS

The feasibility of designing or incorporating a low cost, lightweight stability augmentation system should be explored by the helicopter airframe manufacturers. Today's technology may provide the means to accomplish a goal of significantly improving the handling qualities of their helicopters. Where a hydraulic system is not practical for inclusion in the design, the technology exists to provide the secondary or automatic flight control system functions with small electrical actuators. A reduction in the accident rates will surely follow. When the other safety investment strategies are implemented, the goal of reducing the accident rate by as much as 50% may be realistic.

In 1966, NASA published the results of handling qualities evaluations of seven General Aviation aircraft manufactured in the United States (ref. 11). This investigation revealed that the handling qualities of the class of general aviation aircraft, although generally satisfactory for flight under VMC and instrument flight in smooth air, were degraded when atmospheric turbulence was encountered. Although the particular aircraft designations and manufacturers were not stated, the illustrations of the various types of light airplanes evaluated effectively identified the selected models.

It is recommended that representative classes of light, piston engine and turbine powered helicopters be similarly evaluated to assess their handling qualities and to document the deficiencies. In our opinion, strong recommendations would be forthcoming to improve the handling qualities of this class of helicopter.

APPENDIX A

Comments on Adjunct Safety Issues

Post Crash Fires: Many helicopters involved in survivable accidents have experienced post crash fires that have caused thermal injuries and fatalities to crew and passengers. The Army pioneered the development of crashworthy fuel systems based on the incidence of post crash fires in their fleet of helicopters and the resulting injuries and deaths to crews and passengers. An early historical example involved the OH-13 helicopter. Until the OH-13H was introduced, the incidence of post crash fires in hover accidents was nominal for this particular helicopter. The "H" Model configuration had two "saddle" fuel tanks mounted high behind the cockpit bubble. As operational time was accumulated on this new model, the incidence of post crash fires and thermal injuries increased dramatically in fully survivable accidents. A study, which included the use of a tethered helicopter deliberately crashed from hover, revealed that components of the rotating swashplate (swashplate driver) struck the tanks and slashed them open. The resulting fine fuel spray was easily ignited. As a quick fix for this problem, the Army devised a system to wrap the tanks with a tough nylon fabric impregnated with a resin to seal it to the tanks after wrapping. The objective was to provide some tear resistance to the tanks and reduce the loss of fuel in the event of swashplate contact. Many of these helicopters are still flying today, without any added protection, as Bell 47 models.

The expansion of Army Aviation during the years of the United States' involvement in the Republic of Vietnam led the Army to develop the Crashworthy Fuel System for its fleet of UH-1 and other helicopters. The design was simple, but it prevented many post crash fires and the injuries and fatalities which, in many cases, would have resulted. The fuel bladders were constructed of a heavier, tear resistant rubberized fabric and break away fuel fittings were incorporated in the fuel lines and hoses. These fittings would break loose on impact and seal the lines and tanks to contain the fuel. On the downside, the thicker bladders weighed more and reduced the fuel capacity of the aircraft slightly. For example, a UH-1H (Bell 205) original tank held 220 gallons of jet fuel. After the modified tanks were installed, fuel capacity was 211 gallons or a 4% reduction. This was not too great a price to pay for the significant reduction in thermal injuries and fatalities that resulted from the incorporation of this technology into this large fleet of Army helicopters.

This technology, applied to the civil variants of many Army helicopters, could extend these safety benefits to larger segments of the private and corporate sectors. Amendments to FAR Parts 27 and 29 require that a crashworthy fuel system be included in the design of any helicopter for which a new type certificate has been applied. It does not, however, apply to helicopters certificated prior to the effective date of the amendments. These helicopters, which number in the thousands, will not afford the crews and passengers the vital protection from, and the reduced likelihood of, post crash fires. Retrofit kits could be designed and marketed for the civil sector.

The application of this technology should also be considered for retrofit in the huge fleet of General Aviation fixed wing aircraft. It is true that it would involve considerable expense and result in a small reduction in fuel capacity. This should be factored against the many lives that would be saved in otherwise survivable accidents. The disfiguring and incapacitating burns that result in the survivable "crash and burn" accidents should also be considered when tallying up the true costs of the modifications versus the human misery that could be prevented.

The occurrences of post crash fires for the hover and low speed cases studied were not excessive, but the Army's experience, prior to the installation of the crashworthy systems, was sobering.

Teetering Rotor Systems: As noted in the main body of the report in the Results section**,** the military services had many fatal accidents attributed to mast bumping in the UH-1 series of helicopters that were employed by the thousands. Although a significant number of mast bumping accidents were not noted in this report, it was considered important to describe the conditions conducive to mast bumping for those not familiar with this usually fatal occurrence.

The problem was accentuated and aggravated when the Army began to use nap-of-the-earth and terrain following tactics to avoid the shoulder fired missile threat in the Republic of Vietnam. For many years in Vietnam, the helicopters flew at approximately 1500 feet above the terrain to avoid much of the effective small arms fire (7.62mm). With the introduction of the Russian Strela heat seeking missiles into the combat zone, the tactics changed and put the helicopters "down on the deck." Mast bumping accidents began to occur more frequently and it was learned that they were due to a combination of circumstances. When the pilot pushed the nose of the helicopter down rapidly to stay near or get close to the terrain, such as flying over a ridge, the helicopter rotor experienced less than 1g conditions. This caused large rotor flapping angles. When aggravated by a combination of abrupt control inputs, aft center of gravity, or sideslip, a fatal mast bump could occur. Immediate training remedies were used to make pilots aware of the conditions that caused mast bumping and how to avoid them. In addition, a thick walled mast was developed to replace all of the rotor masts in the entire fleet of UH-1 helicopters. The intent was to be able to sustain a light mast bump without shearing. Hub springs were also incorporated in the design of these teetering rotor helicopters to aid in controlling the flapping of the main rotor.

While the lessons of this conflict only bear peripherally on the discussion at hand, they do begin to apply in the low airspeed regime and would likely find even greater significance in extending this work to an analysis for the forward flight regime.

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(650) 604-2968

14. ABSTRACT
Because of increasing accident rates in Army helicopters in hover and low speed flight, a study was made in 1999 of accidents which could be attributed to inadequate stability augmentation. A study of civil helicopter accidents from 1993–2004 was then undertaken to pursue the issue of poor handling qualities in helicopters which, in almost all cases, had no stability augmentation. The vast majority of the mishaps studied occurred during daylight in visual meteorological condition, reducing the impact of degraded visual environments (DVE) on the results. Based on the Cooper-Harper Rating Scale, the handling qualities of many of the helicopters studied could be described as having from "very objectionable" to "major" deficiencies. These costly deficiencies have resulted in unnecessary loss of life, injury, and high dollar damage. Low cost and lightweight augmentation systems for helicopters have been developed in the past and are still being investigated. They offer the potential for significant reductions in the accident rate.

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